

# **3D PMN Flexensional Stave Modeling\*\***

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**The Penn Stater Conference Center**

**11th-13th April 2000**



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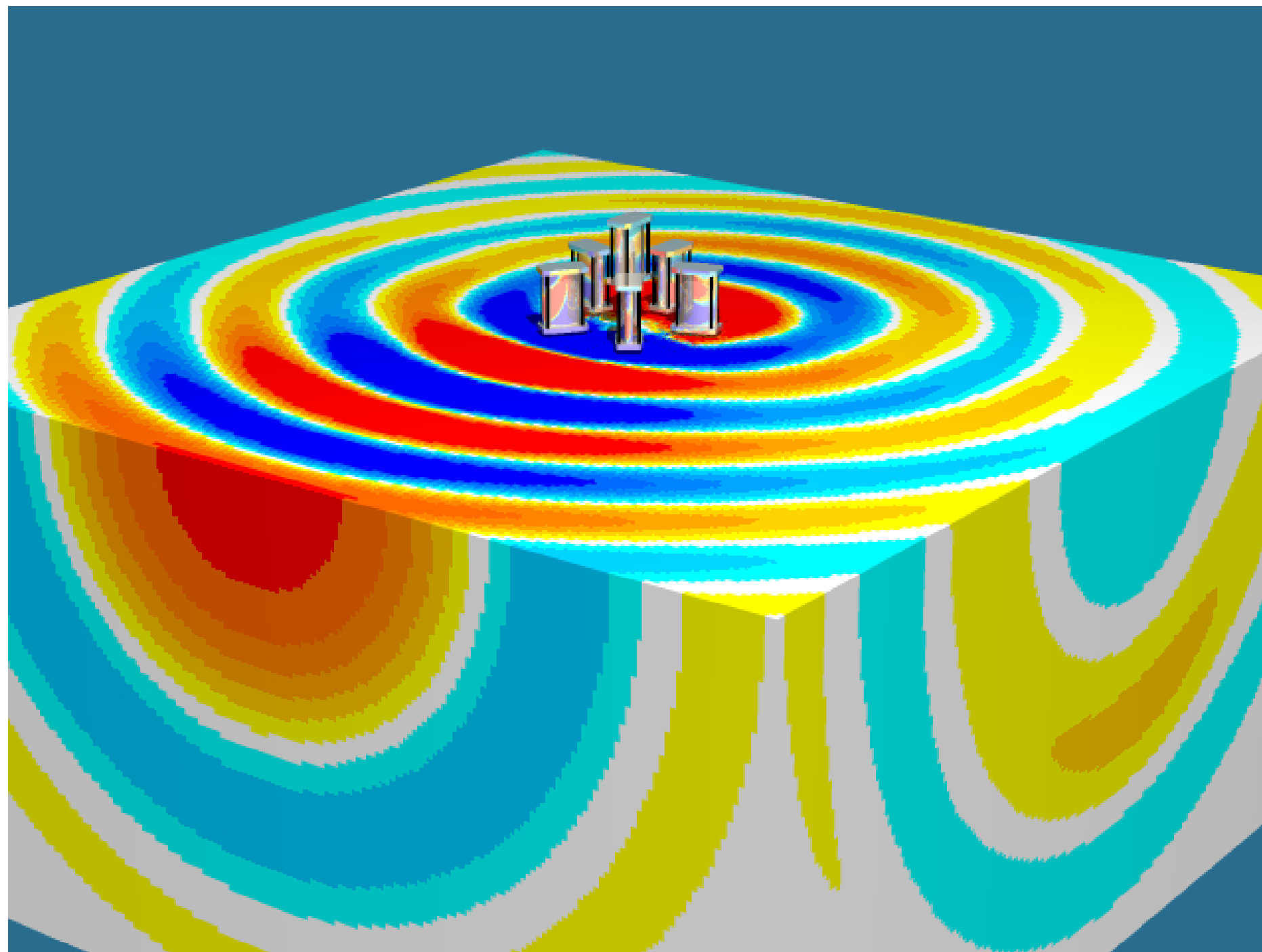
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## SONAR PROJECTOR APPLICATIONS

- Require high power and broadband
  - To address general needs of Navy
- Consider PMN-driven projector
  - Staves of butted Class IV flextensional shells
  - Array composed of multiple staves
- Projector arrays within tow body
  - Fiberglass/metal structures surround arrays



Radiated acoustic field from a flextensional array sonar projector in a 2x2 m cube of water (upper half removed for viewing). An absorbing boundary condition effectively passes sound out of the model with negligible reflection. Drive signals to each flextensional transducer are phased to project the principal beam out the left front face.

## Projector Issues

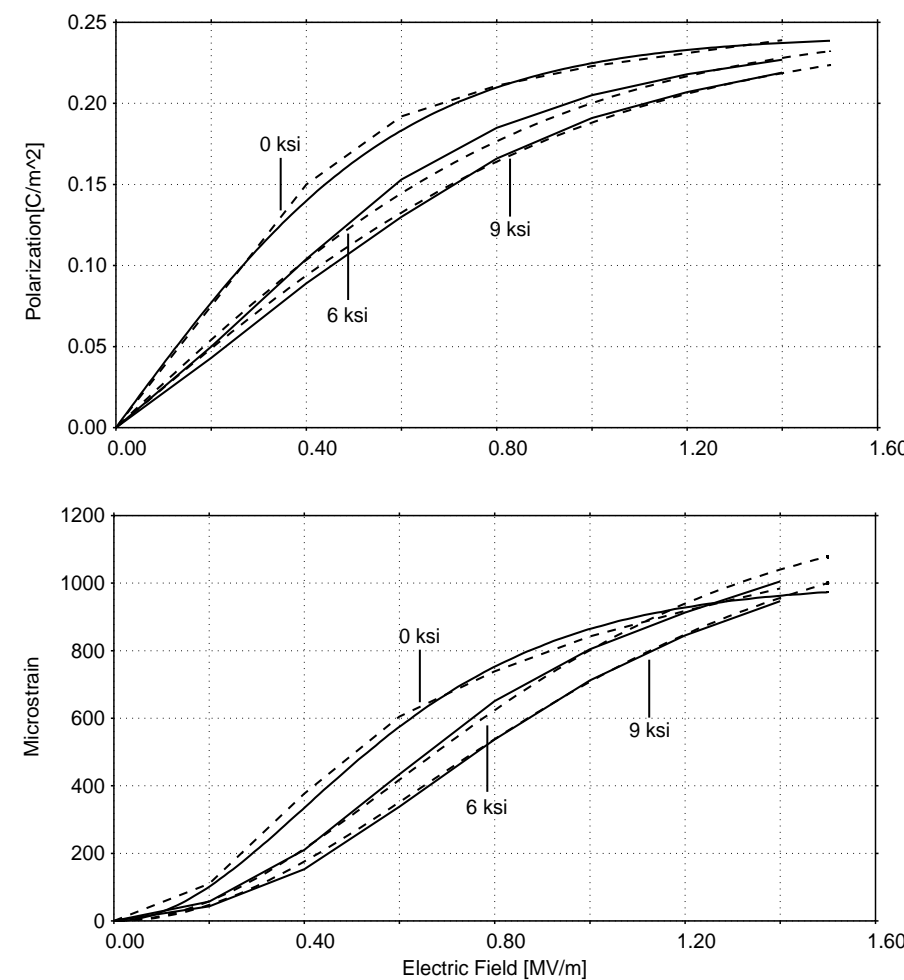
- Need to explore and understand:
  - Nonlinear PMN drive behavior
  - Broadband stave response
  - 3D acoustical coupling between staves
  - Effects of tow body
  - Overall design and integration

## Why 3D Time-Domain Modeling?

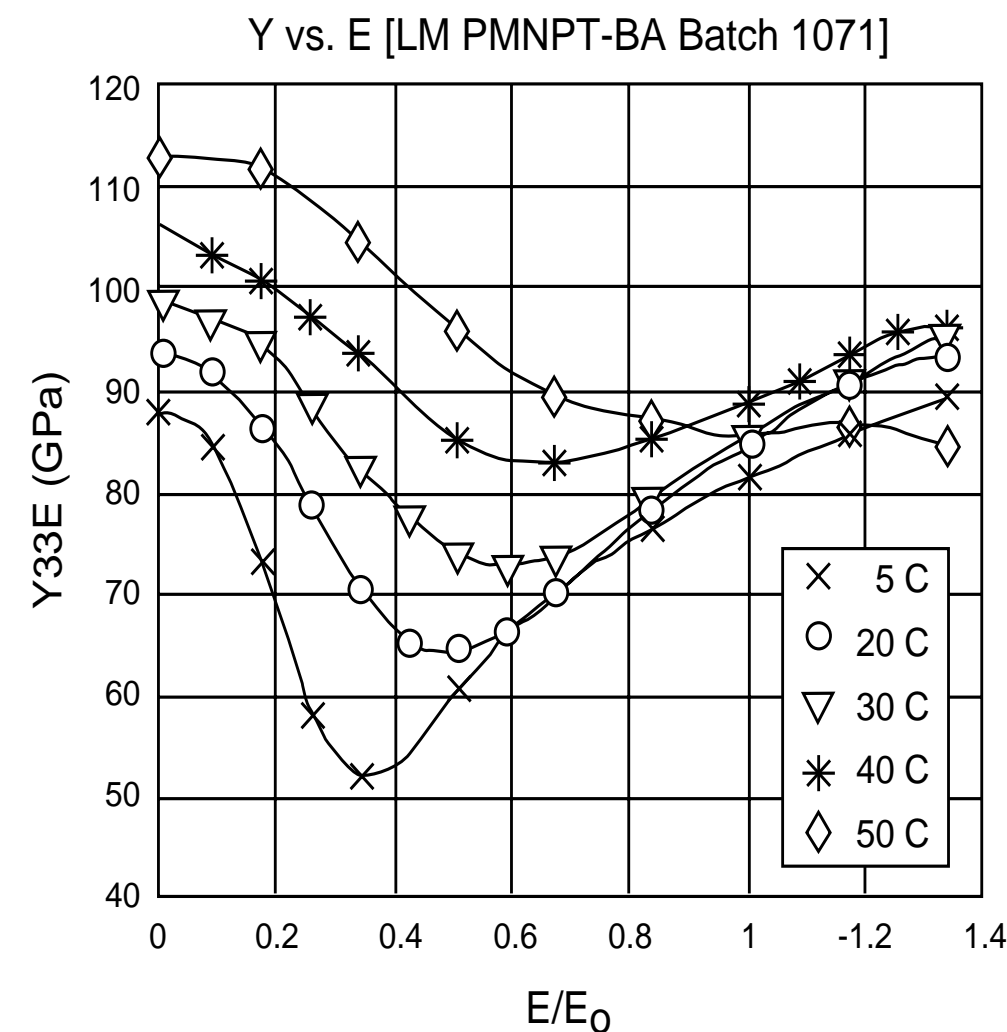
- Exhaustive prototype testing costs much more than numerical simulations
- Time-to-deployment is critical
- Valuable for test interpretation and planning

## Modeling Justification

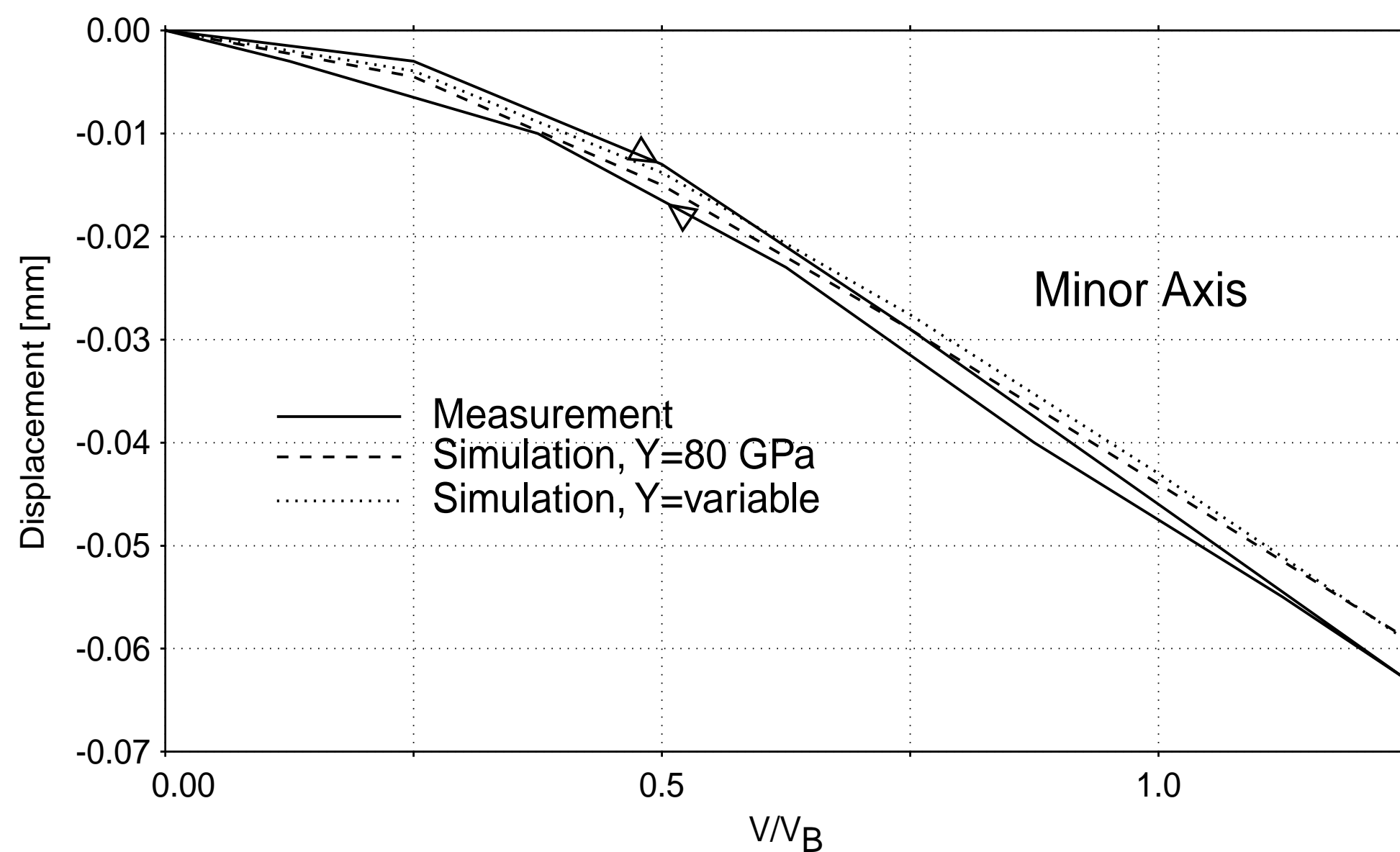
- PZFlex modeling software validated
  - Have reasonable confidence in results
    - ♦ i.e. appreciate uncertainties and limits
- Hardware makes large-scale models feasible
  - 2,4, or 8 processor PCs
    - ♦ parallel processing
- Greatest impact when modeling used at beginning of design process



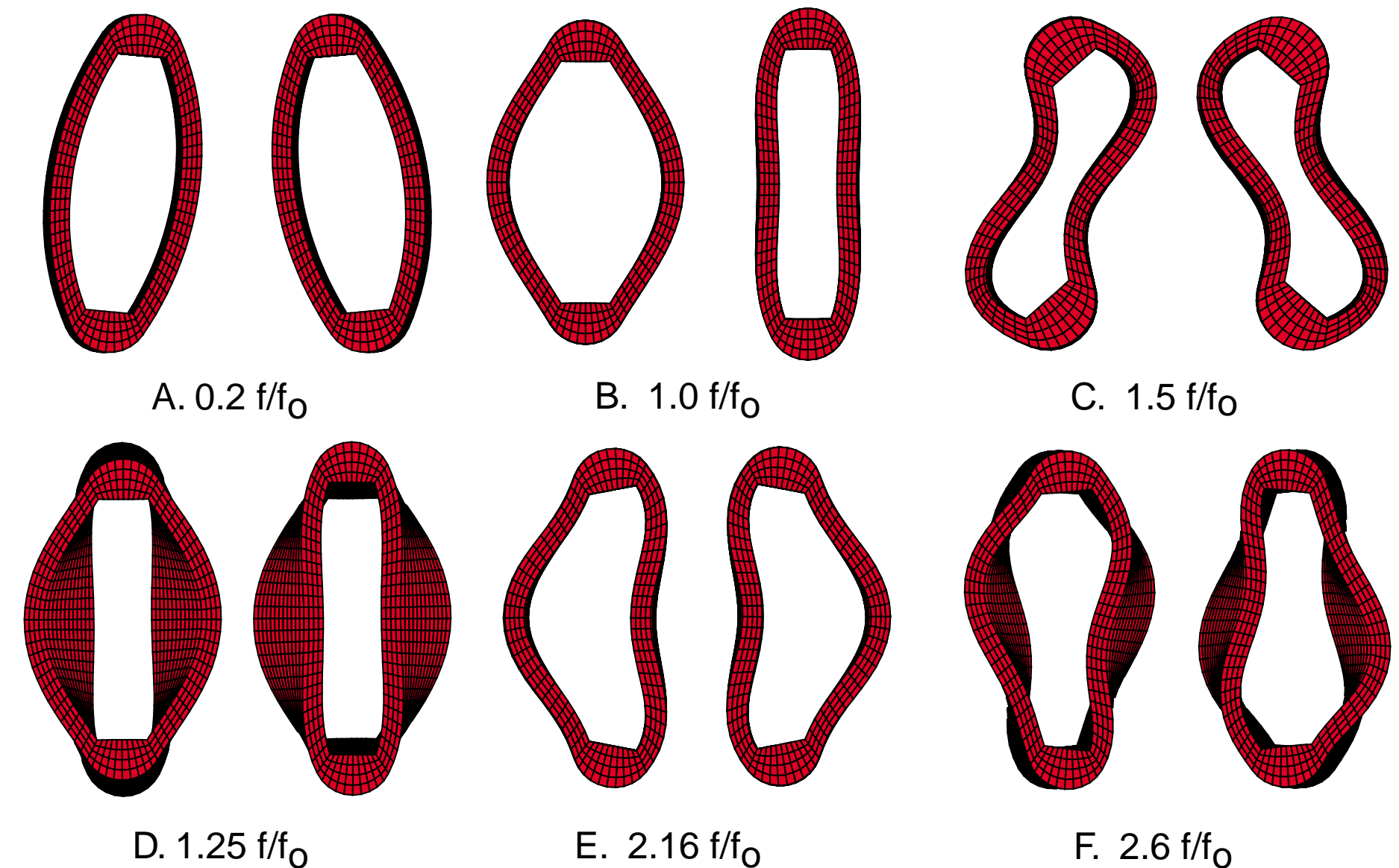
Hom-Shankar constitutive model fits to NUWC polarization and strain data at 0,6,9 ksi prestress, 20°C.



NUWC measurements of Young's modulus  $Y$  versus electric field bias in PMN at various temperatures.



Static shell displacement across the minor shell axis due to bias voltage: comparisons of Lockheed Martin measurements and PZFlex simulations.

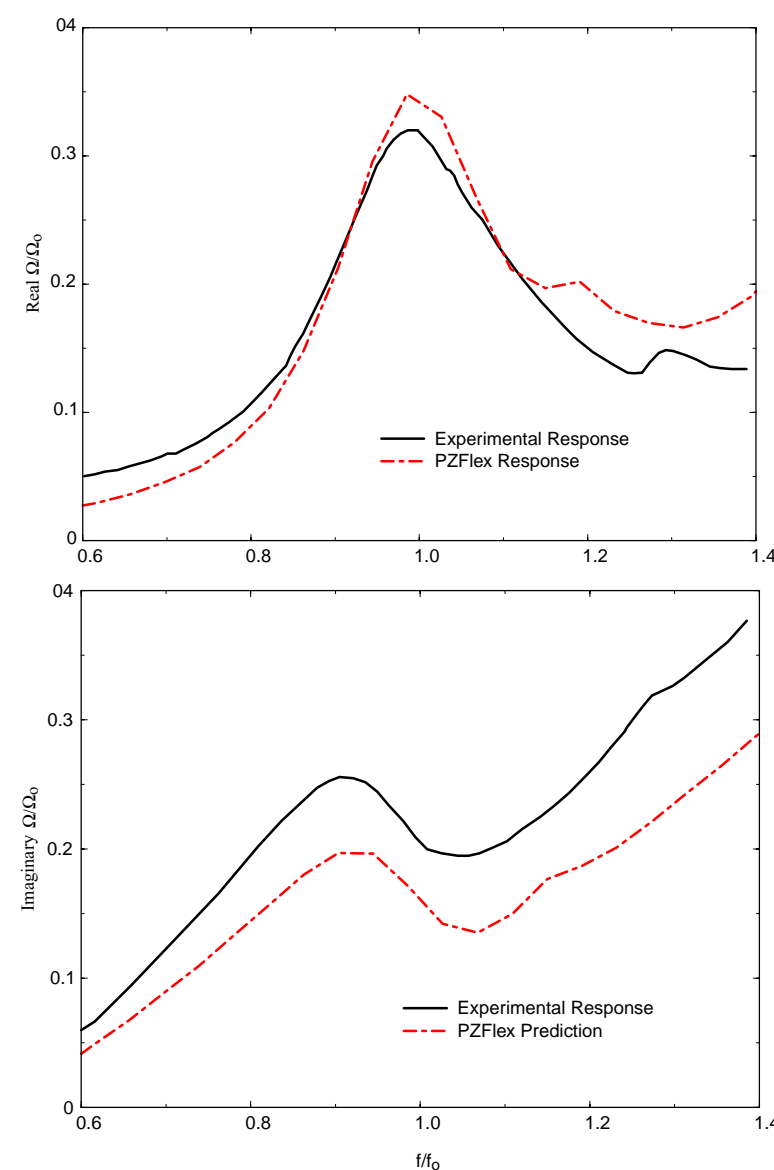


Flextensional shell mode shapes at principal resonances calculated in air. All frequencies are within 1.5% of Lockheed Martin acceleromoter measurements.

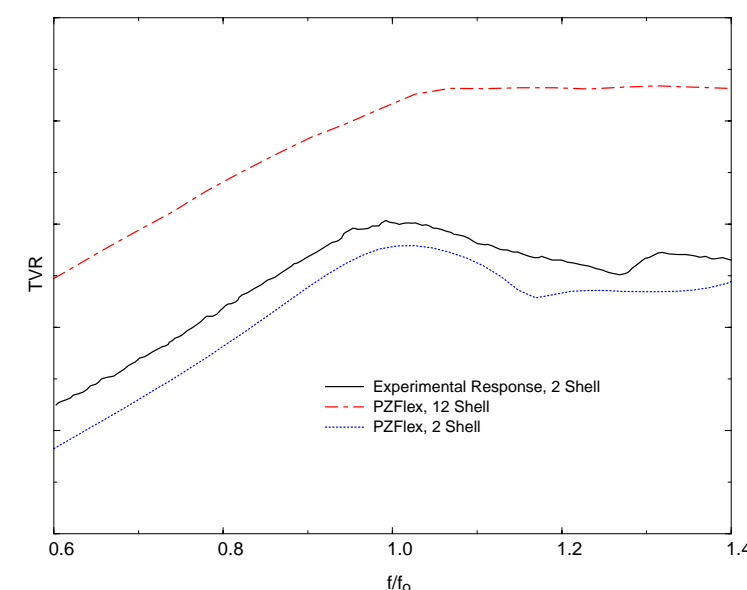
## Constitutive Data, Model & Validation

- **NUWC measurements of PMN**
  - **Very low frequency data available**
    - ◆ Lynn Ewart, et.al: Underwater Transducer Materials Resource
- **Dynamic data forthcoming**
  - ◆ Elizabeth McLaughlin's Sonar Frequency Characterization Rig
- **Hom & Shankar's tanh model for PMN**
  - Reasonable fit to low frequency data
  - Robust model offers further opportunities
    - ◆ adding hysteresis but not necessary at present
- **Validation against Lockheed Martin data**
  - Shell vibration modal frequencies
  - Shell-stack displacement due to static bias

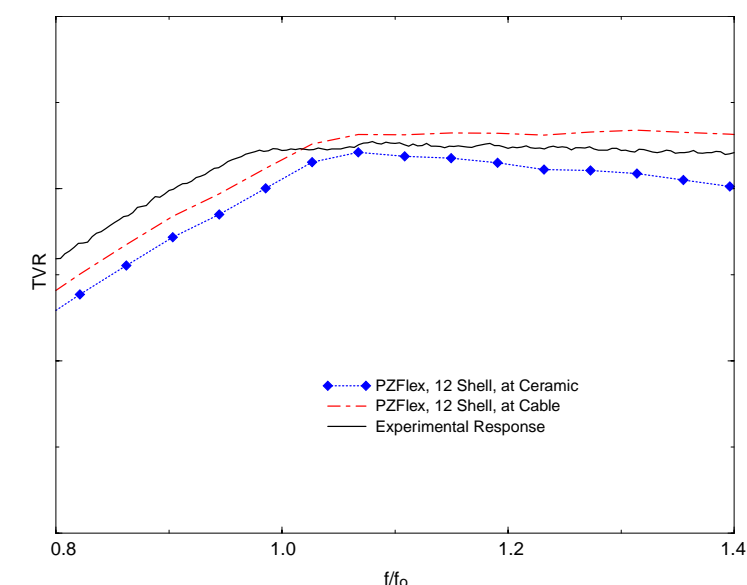




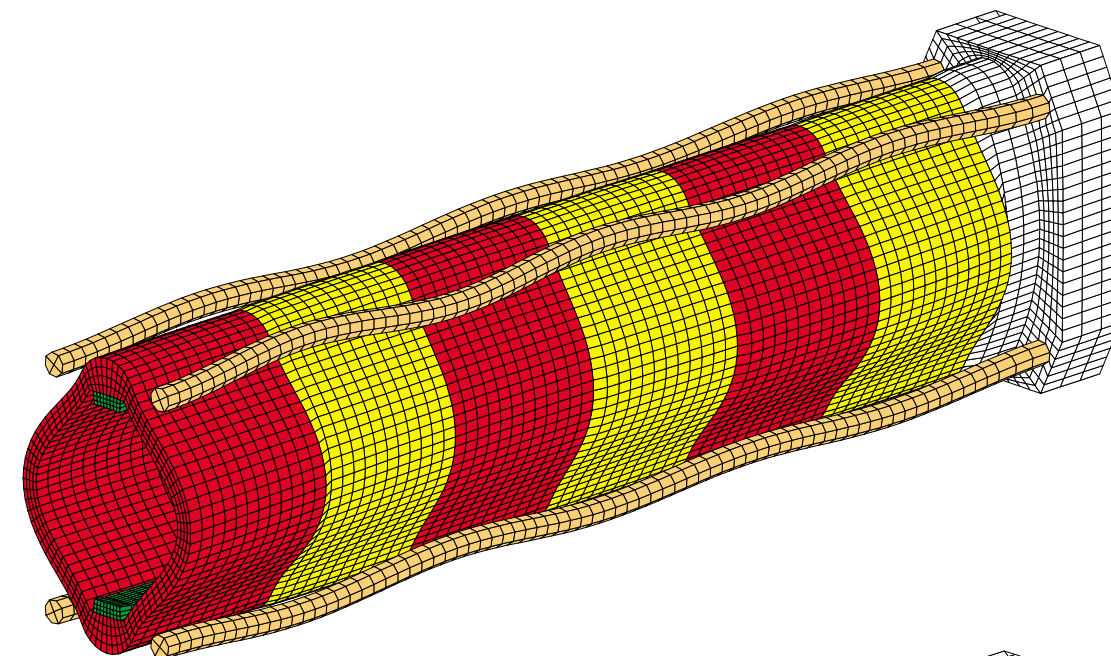
Comparison of measured and simulated admittance in water for the 2-shell stave with cable.



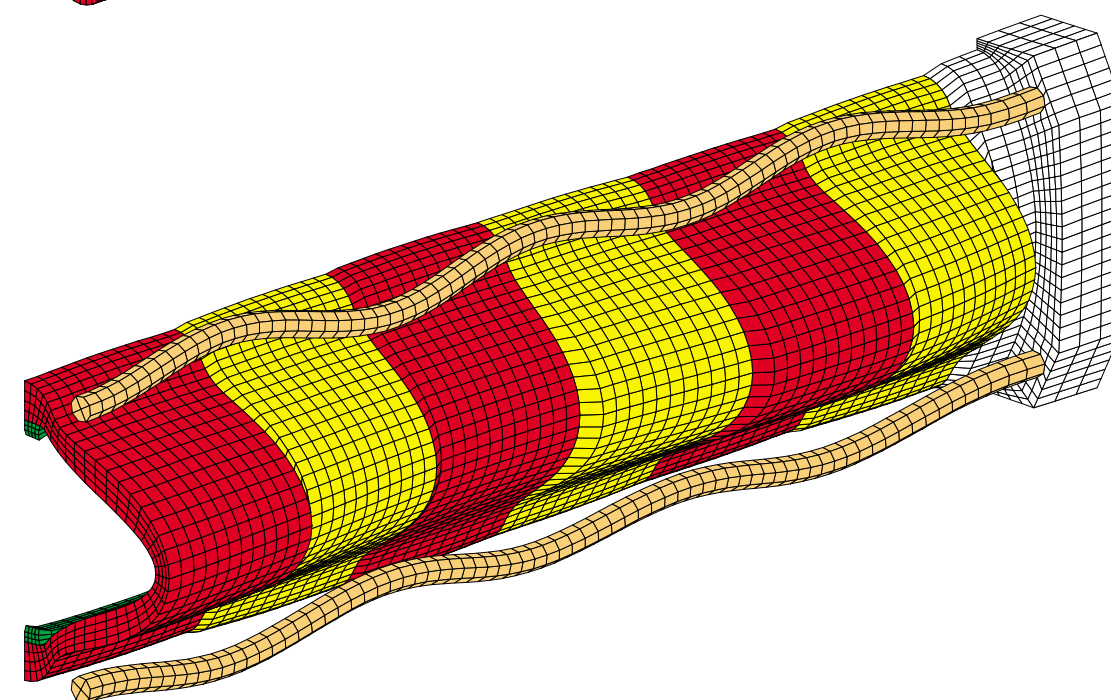
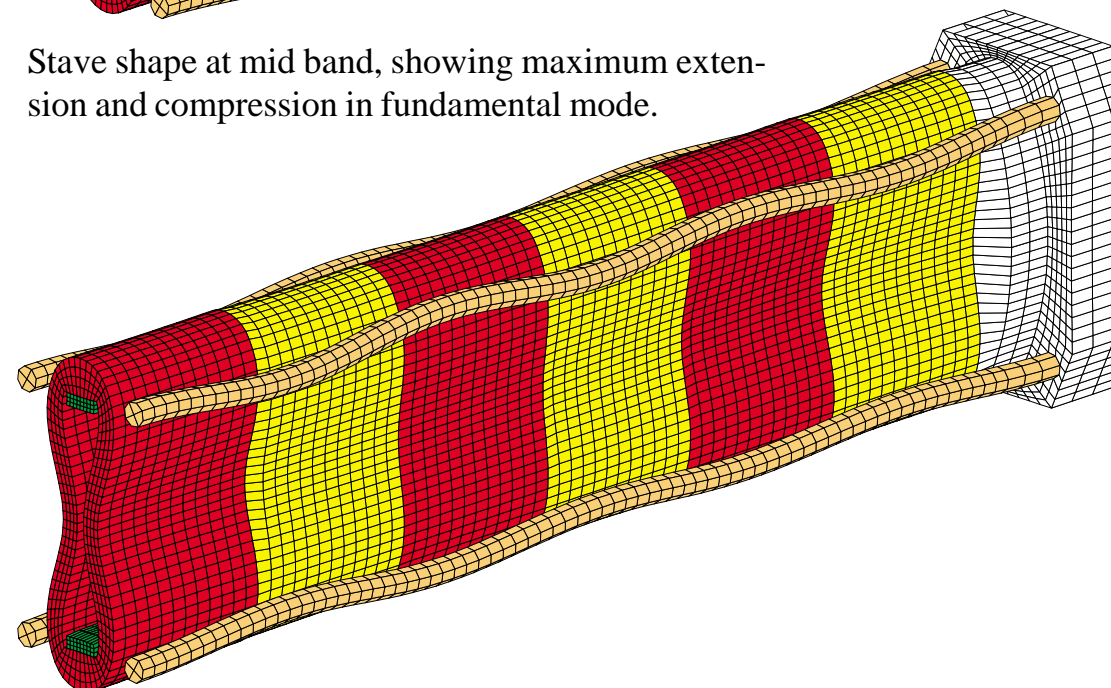
Comparison of measured and simulated TVR in water for the 2-shell stave.



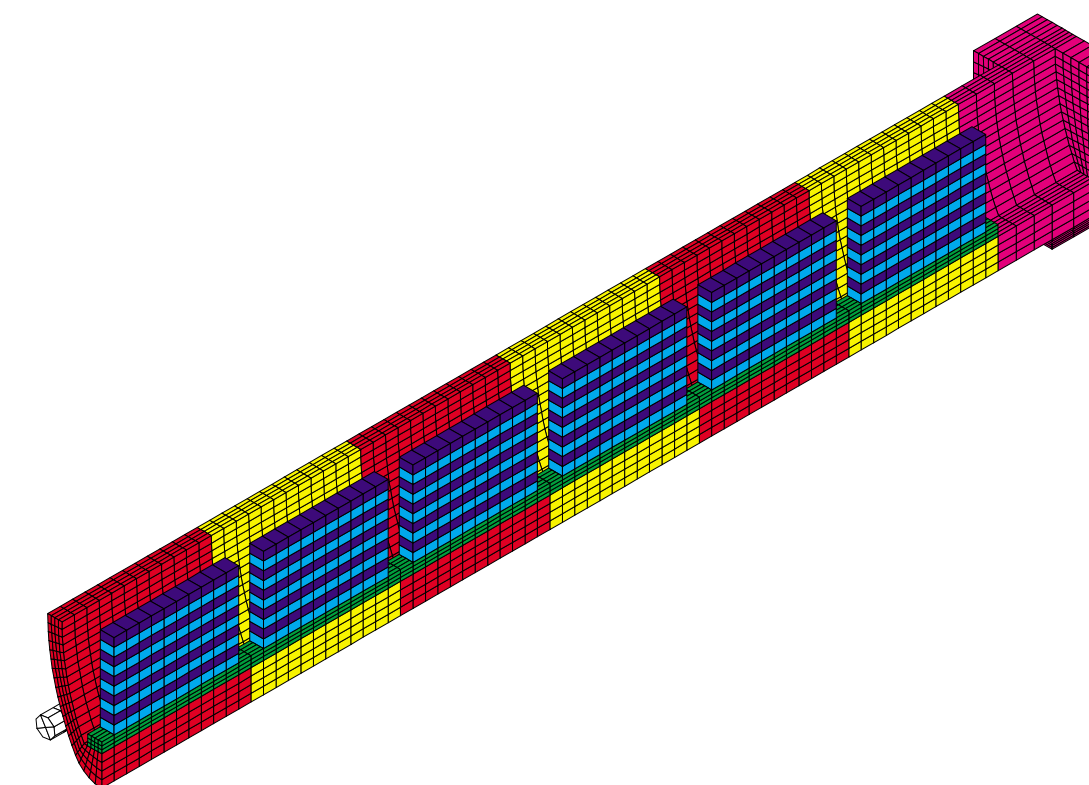
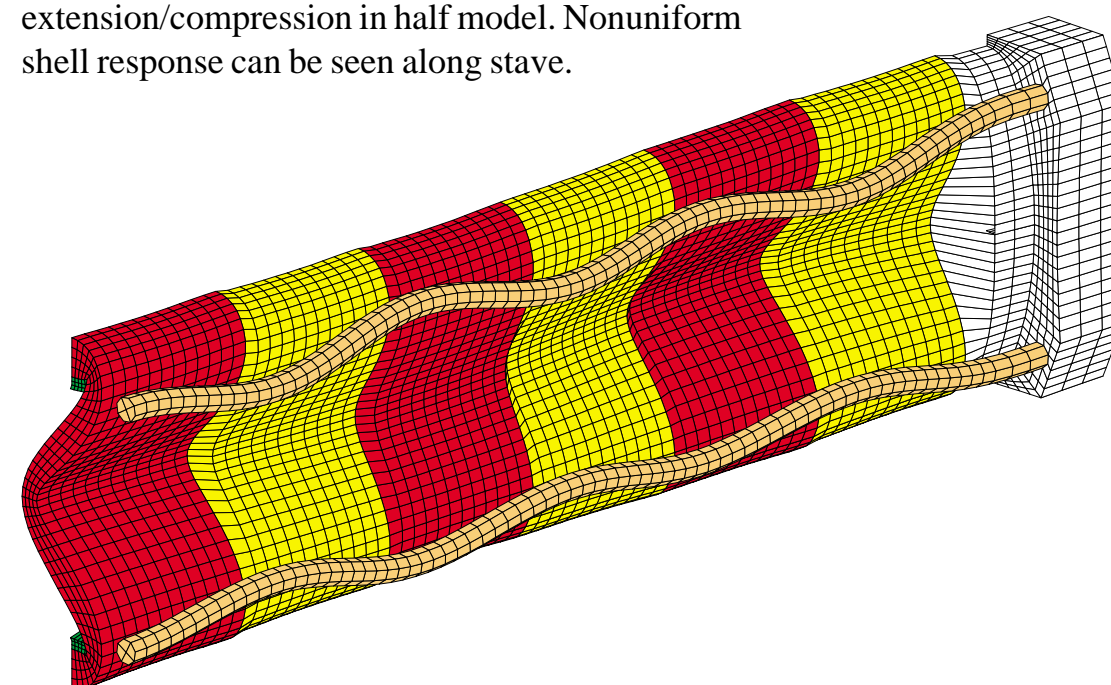
Comparison of measured and simulated TVR in water for the 12-shell stave.



Stave shape at mid band, showing maximum extension and compression in fundamental mode.



Stave shape at high band, showing maximum extension/compression in half model. Nonuniform shell response can be seen along stave.



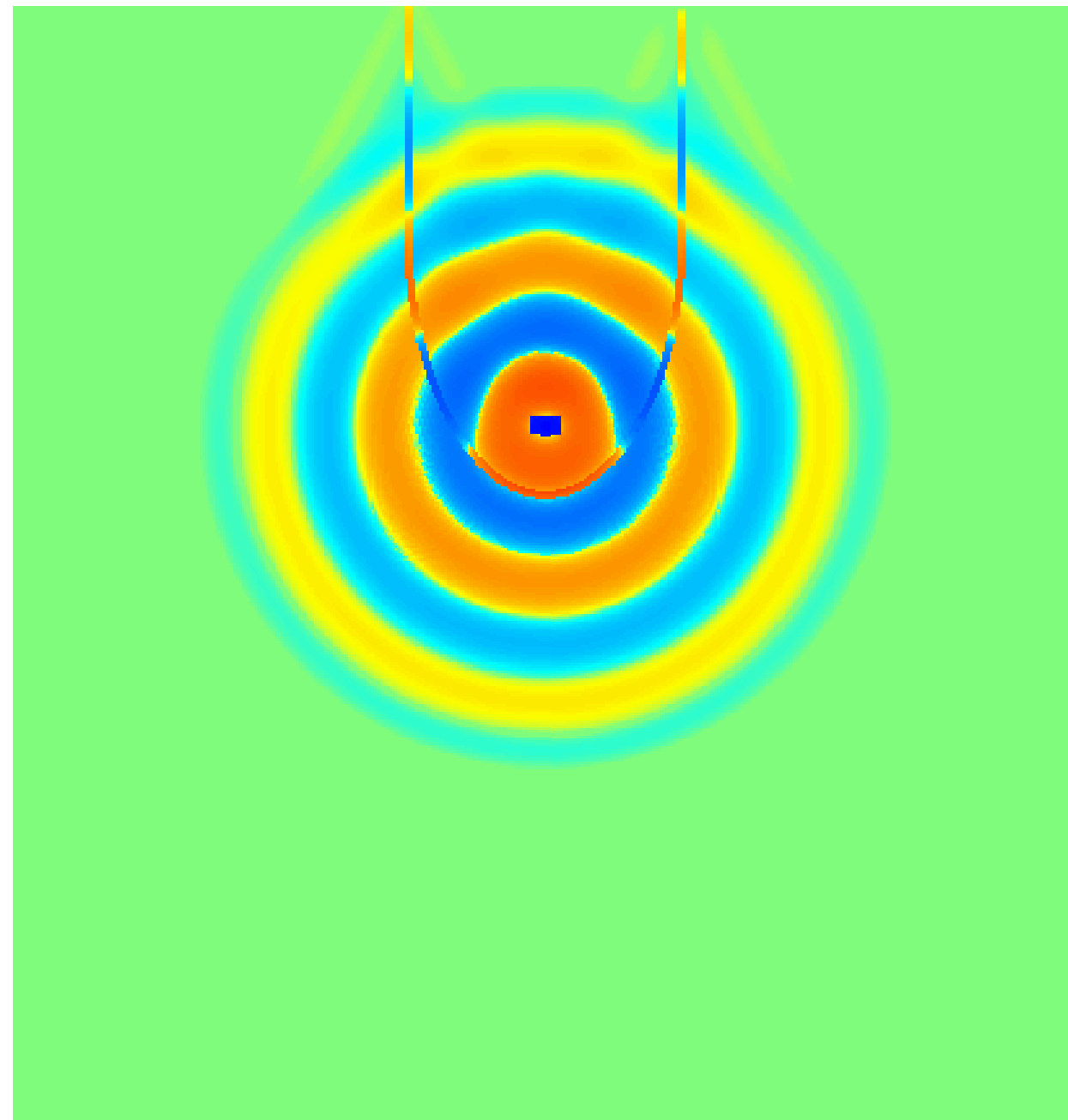
## Stave Response Validation

- Seneca Lake stave tests
  - Two-shell and twelve-shell data
- Comparisons of admittance and TVR
  - Differences: 13% admittance; 1-2dB TVR
- Uniform mode shapes in mid band
  - Nonuniformity in high band
- Cable analyses by Jim Griffith (E&H Resources, Inc., Phoenix)

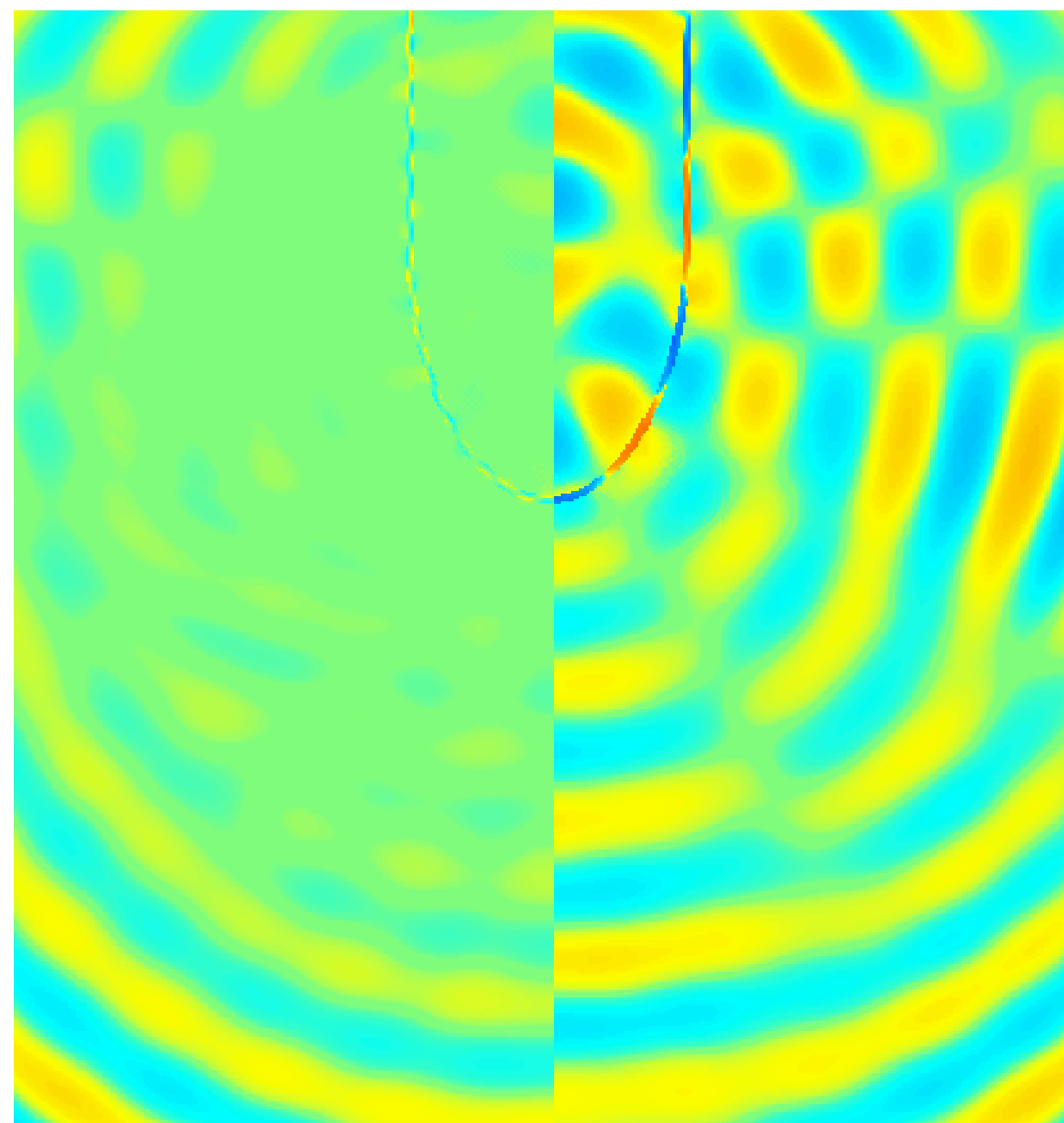
## Conclusions

- PMN stave modeled reasonable well
  - Always room for improvement
    - ◆ high frequency PMN data will help
- Confidence in overall system models
  - Multi-stave arrays with electronics
  - Arrays in 3D tow body
- PZFlex to be installed at NUWC
  - Facilitate modeling earlier in system cycle

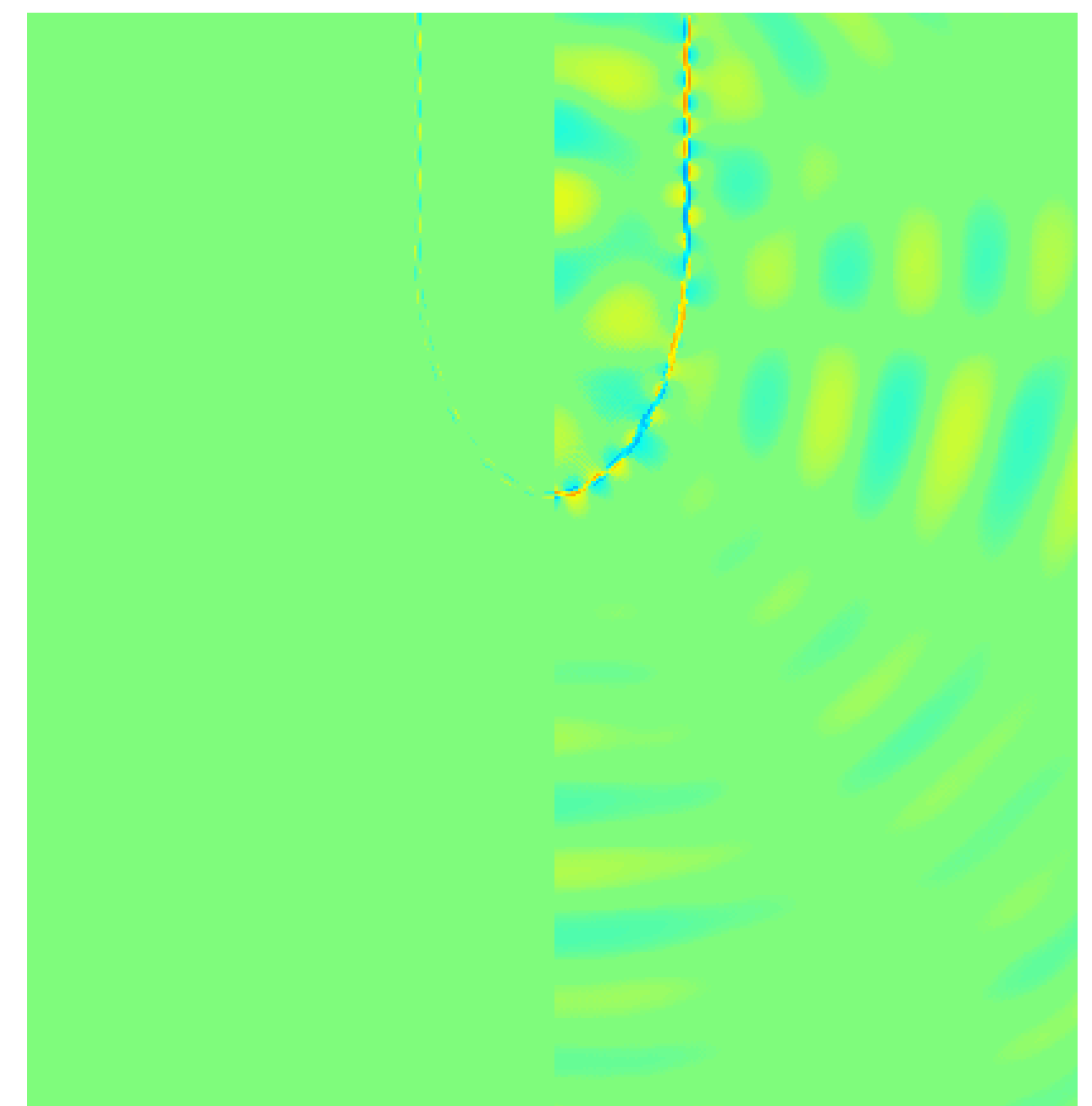




$t = 2 t_0$



$t = 8 t_0$



$t = 16 t_0$

Comparison of propagation through fiberglass tow body with and without joint in shell (at top of snapshot). Half on left is without joint (transmitting) and half on right is with free joint. Exterior water boundaries transmit waves out of model. Lower curves show pressure spectrum (left) and insertion loss vs angle (right).

## Tow Body Effects

- Preliminary 2D study of fiberglass shell
  - Insertion loss and flexural (Lamb) waves
  - Using measured anisotropic properties
- Insertion loss minimal
  - 5-10%, increasing with thickness
- Lamb waves can modulate transmission
  - Depends on joint design
  - Compare transmitting and free joint

